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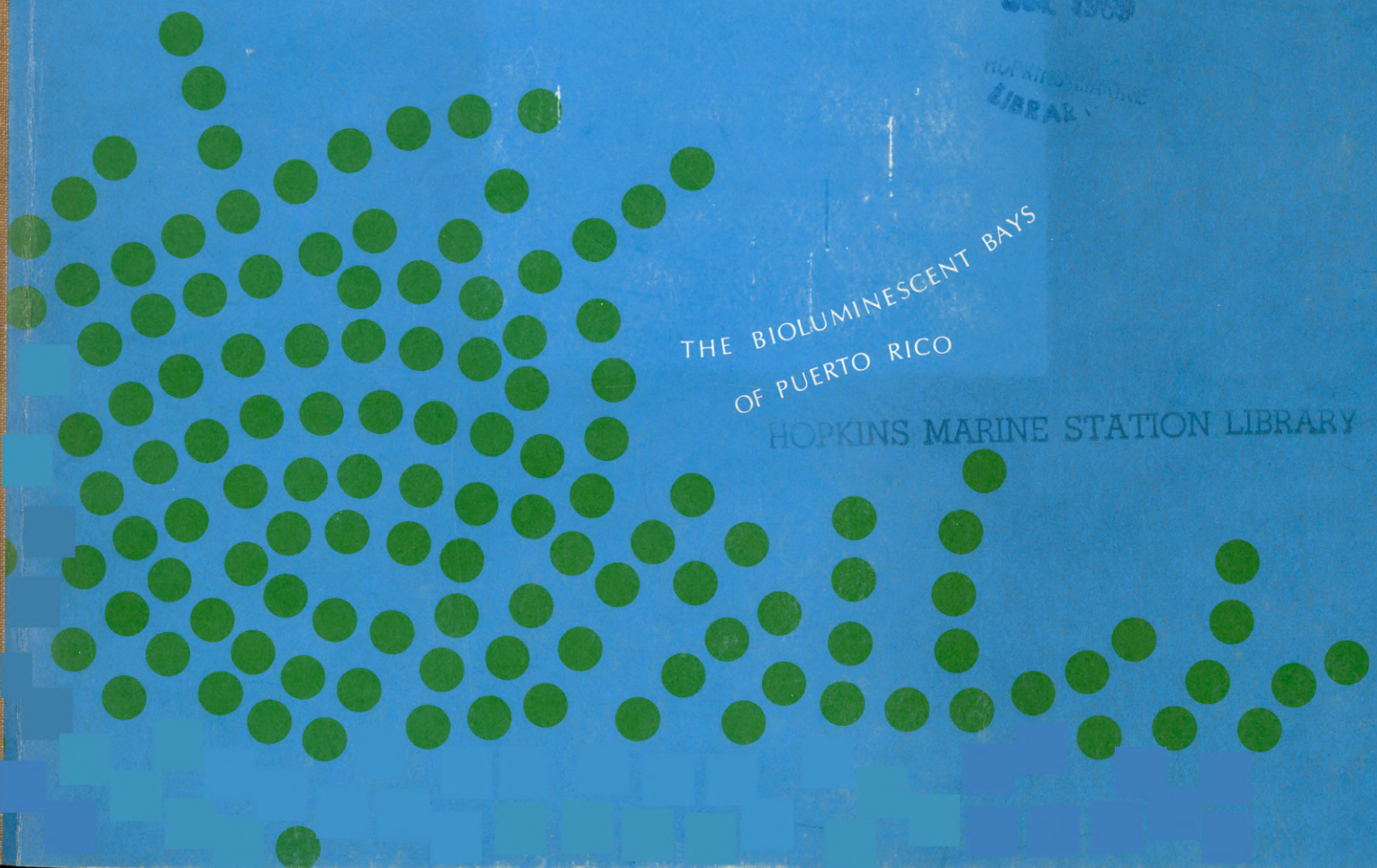

THE BIOLUMINESCENT BAYS OF PUERTO RICO

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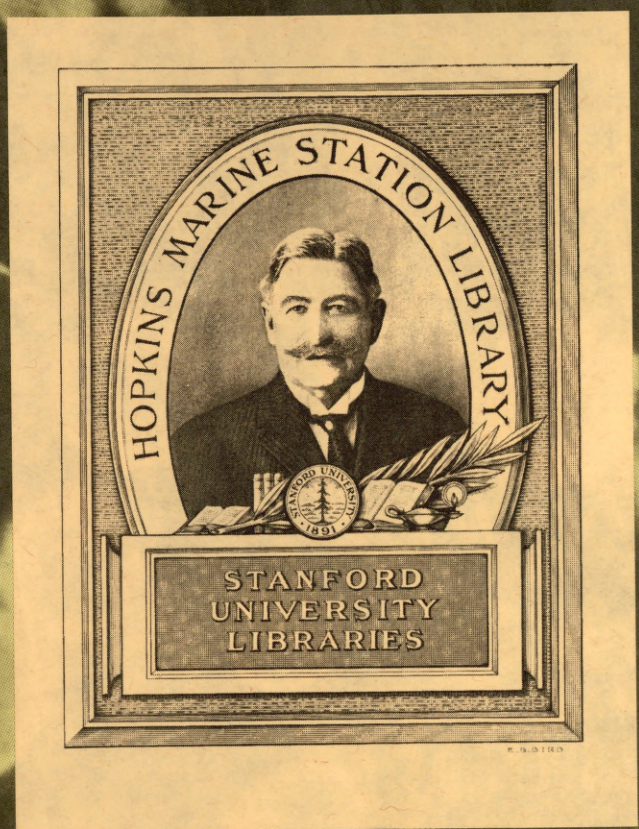
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THE BIOLUMINESCENT BAYS OF PUERTO RICO

A plan for their preservation and use

1968
Prepared for the Commonwealth of Puerto Rico by the
U.S. DEPARTMENT OF THE INTERIOR National Park Service

The plan which follows was developed for the Commonwealth after a field trip to the area in April 1967. The National Park Service planning team consisted of Chester L. Brooks (Team Captain), Robert G. Johnsson (ecologist), Frederick Ley, Jr. (landscape architect), and Julio Marrero-Nuñez (Superintendent, San Juan National Historic Site). Dr. Howard T. Odum of the University of North Carolina served as a consultant to the team during part of the study.

Mr. García-Santiago made the full resources of his organization available to the study team, and his efforts are greatly appreciated. Salvador Capestany of his staff was most helpful in arranging the complex logistics for the team. On the Vieques Island portion of its reconnaissance, the team was accompanied and aided by Juan G. González of the Institute of Marine Biology, University of Puerto Rico, Mayagüez.

Thanks are also extended to Dr. George L. Clarke of Harvard University and the Woods Hole Oceanographic Institution who read the original manuscript and offered several helpful suggestions.

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A launch traces a luminous path through night-shrouded Bahía Fosforescénte.

Three small bays along the arid south coasts of Puerto Rico and Vieques Island harbor one of the world's most remarkable and beautiful displays of marine bioluminescence. The startling luminescence of these bays, their rarity over the earth, and their importance to marine biology make them internationally significant. To Puerto Rico they offer the opportunity to preserve and develop an outstanding visitor attraction.

Awak'd before the rushing prow,
The mimic Fires of ocean glow
Those lightnings of the wave;
Wild sparkles crest the broken tides,
And flashing round the vessels' sides
With elfish lustre lave
While far behind, their livid light
To the dark billows of the night
A blooming splendour gave.

Sir Walter Scott,
Lord of the Isles

From the earliest times men have observed the strange "burning of the sea." The ancient Greeks were the first to record the startling apparition in which the sea seems to glow with a mysterious inner light. Ever since, the literature of the sea has abounded with references to it.

In the early 1600's, on his second voyage to the East Indies, John Davis commented that near Ascension Island, "I thinke I saw the strangest Sea, that ever was seene: Which was, That the burning or glittering light of the Sea did Shew to us, as though all the Sea over had been burning Flames of Fire."

Johann Forster, the naturalist on Capt. James Cook's voyage around the world from 1772 to 1775, wrote:

"Scarcely had night spread its veil over the surface of the ocean, when it had the appearance of being all over on fire. Every wave that broke had a luminous margin or top; wherever the sides of the ship came in contact with the sea, there appeared a line of phosphoreal light. The eye discovered this luminous appearance every where on the ocean; nay, the very bosom of this immense element seemed to be pregnant with this shining appearance."

Charles Darwin, in his book, *Voyage of the Beagle* (1832), described the fires of the sea in the South Atlantic: "The vessel drove before her bows two billows of liquid phosphorous, and in her wake she was followed by a milky train. As far as the eye reached, the crest of every wave was bright. . . ."

C. W. Thomson, an officer aboard the *Challenger* on its 1877 voyage, recorded one spectacular display:

"On the night of the 14th the sea was most gloriously phosphorescent to a degree unrivaled in our experience. A fresh wind was blowing and every wave and wavelet, as far as one could see from the ship on all sides to the distant horizon flashed brightly as they broke. Astern of the ship, deep down

where the keel cut the water, glowed a broad band of blue, emerald green light from which came streaming up or floating to the surface, myriads of yellow sparks, which glittered and sparkled against the brilliant cloud light below, until both mingled and died out astern far away in our wake. Ahead of the ship, where the old bluff blows of the 'Challenger' went ploughing and churning through the sea, there was enough light to read the smallest print with ease. It was as if the 'Milky Way' as seen through a telescope, 'scattered in millions like gleaming dust', had dropped down into the ocean, and we were sailing through it."

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A swimmer churns the water into a luminous froth.

These fires of the sea which so fascinated early seamen mystified the scientific world for centuries. Though it had been known that the sea contained numerous large animals that were luminescent, it was not until the mid-19th century that the living nature of the "burning sea" was understood. With the advent of careful observations and good microscopes, this strange phenomenon was found to be caused by blooms or periodic bursts in population of tiny, free-floating sea creatures called dinoflagellates. These minute bits of life drift with the vagaries of wind and wave and, when disturbed, produce a tiny spark of chemical light. When large numbers of dinoflagellates concentrate, their combined luminescence causes the disturbed sea surface to glow with a steely blue-white light.

The "burning of the sea" is most often encountered in tropical waters but is by no means confined to these regions. It comes and goes from place to place and from time to time with the changing concentrations of the dinoflagellates. The underlying environmental fluctuations responsible for the varying dinoflagellate populations, still little understood, are the cause of the normally fleeting nature of the phenomenon.

Only in a few places in the world are the conditions which support large populations of dinoflagellates constant enough throughout the year to permit the fires of the sea to be seen regularly in the same place over prolonged periods. Three such places are found along the southern coasts of Puerto Rico and nearby Vieques Island. These are small and shallow pocket-shaped bays: Bahía Fosforescênte and Bahía Monsio José on the southwest coast of Puerto Rico near the village of La Parguera, and the somewhat larger Caño Hondo on the south coast of Vieques Island. In these bays light-emitting dinoflagellates are heavily and regularly concentrated. Within them, on any night of the year, can be found one of the world's most startling and remarkable displays of marine bioluminescence.

The bays are entered in a small boat. Approaching through the night, a faint

luminescence rises in the boat's wake, and an occasional tiny spark of light can be seen in the agitated water alongside. Even in the open sea near the bays there are usually large numbers of the light-producing dinoflagellates.

Upon entering the bay, the propeller immediately churns the water into a bluish-white radiance, and the boat's wake glows brightly. The bow waves billow out in sharp, luminous lines. The glow is reflected in the passengers' faces and is bright enough, in fact, to read by.

As the boat churns through the bay, volleys of rocket-like streaks, resembling fireworks, radiate away from the boat. It soon becomes apparent that these luminous streaks are the paths of fish fleeing from the advancing boat. The frightened movements of the fish agitate the dinoflagellates near them into a bright glow. Occasionally a fish, usually a halfbeak, breaks into a wild jump in its dash to escape the boat, producing a meteoric trail of light which ends in a violent, luminous splash as it falls back into the water.

When the motor is turned off, the boat's waves fade away. All is inky black and still. On a moonless night, the best time to view these bays, the boat seems strangely suspended between heaven and earth. The mangrove forest fringing the bay encloses the dark water in an even blacker frame. The stars twinkle silently above. Looking over the edge of the boat into the quiet water, one sees the occasional faint spark of a dinoflagellate. Such spontaneous flashes are probably stimulated by the collisions of these minute creatures with each other or with other bits of flotsam in the water. Slowly stirring the still water with your hand causes a burst of bright sparks. Your hand glows momentarily when some water is scooped up, and then it slowly fades, as fiery beads trickle away. A stone tossed into the water lands in a splash of flame.

To row a boat through these waters is truly a bizarre experience. Each oar-stroke beats the water into luminescence, and "liquid fire" drips from the oars as they are lifted. A swimmer in the bay is a ghostly figure, strangely outlined in the vivid glow of the waters. One of the most exciting scenes occurs on a dark, rainy night. Each raindrop striking the water's surface produces a spot of light, and the whole bay boils from shore to shore with a bluish-white light.

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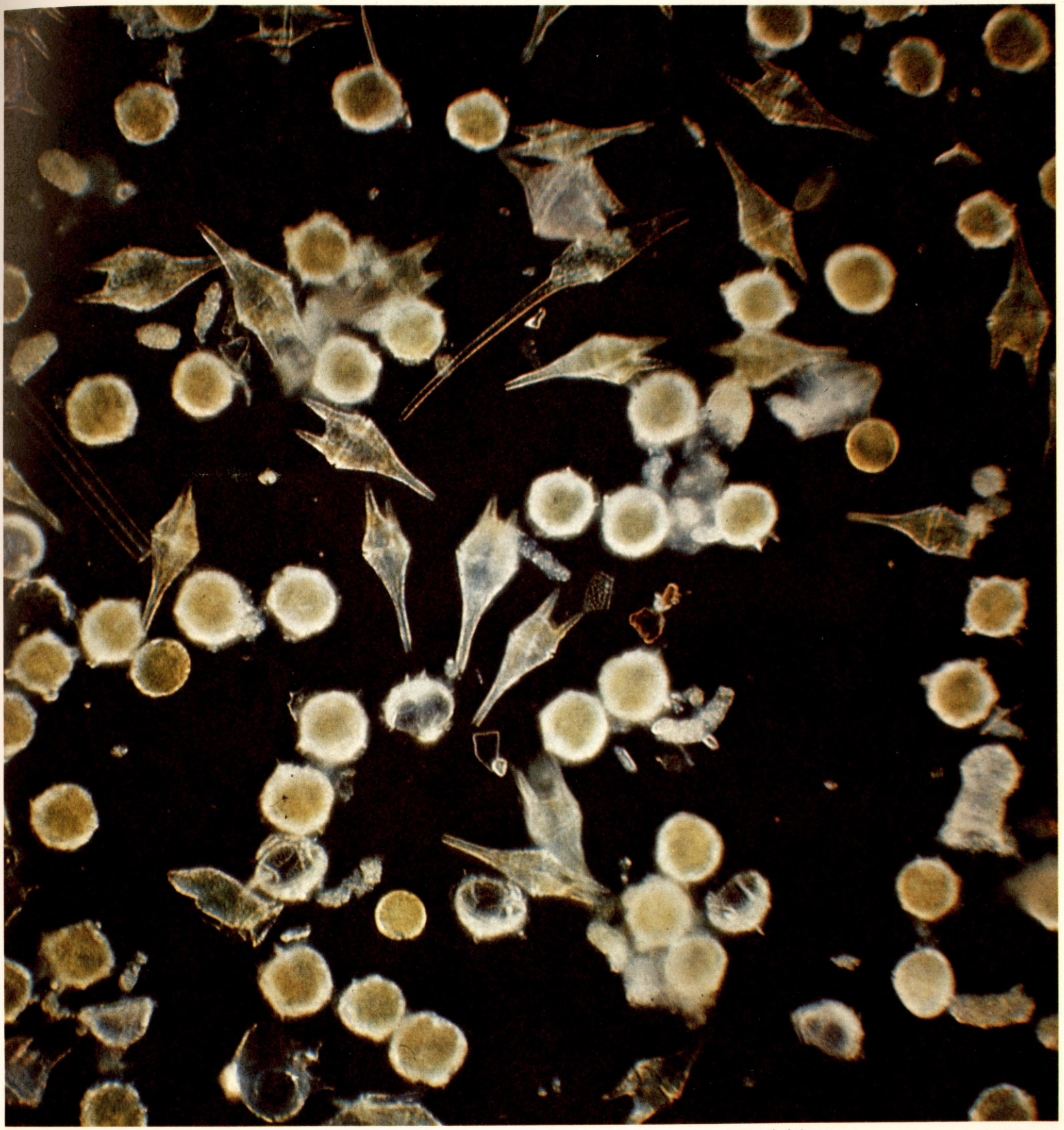


Microscopic life from Bahía Fosforescénte, magnified 250 times. The numerous rounded forms are *Pyrodinium bahamense*, the dinoflagellate responsible for the bay's luminescence.

And when I remember, how many questions I have asked navigators about the luminousness of the sea; and how in some places the sea is wont to shine in the night as far as the eye can reach; at other times and places, only when the waves dash against the vessel, or the oars strike and cleave the water; how some seas shine often, and others have not been observed to shine; how in some places the sea has been taken notice of, to shine when such and such winds blow, whereas in other seas, the observation holds not; and in the same tract of sea, within a narrow compass, one part of the water will be luminous, whilst the other shines not at all. . . .

Robert Boyle, 1627-91.

The bioluminescence of these remarkable bays is caused by the unusually large populations of luminescent dinoflagellates that inhabit them. These tiny forms of marine life are in many ways puzzling creatures. For years biologists have argued as to their true nature, for they seem to be neither plant nor animal but a combination of both. Though they contain chlorophyll and can manufacture their own food like any green plant, they possess the power of animal locomotion. By rapidly beating two whiplike hairs, they propel themselves about their watery realm. But their small size, about 1/500 of an inch, dictates that the control they have over their movement will be poor. They drift in the upper reaches of the sea at the mercy of wind, wave, and current. They do seem able, however, to control their vertical position to some extent, rising a few feet toward the surface in the early evening and sinking down a bit to spend the daylight hours.

Several kinds of dinoflagellates have been collected from these bays, but not all possess the power of light production, and of those that do, only one is present in any numbers. It is the organism called *Pyrodinium bahamense* (literally, the "whirling fire creature of the Bahamas"), and the unusual character of these bays must be attributed solely to its presence there.

The mechanism of light production in *Pyrodinium* is complex and only partly understood, although its chemical nature has been clearly demonstrated. The minute flash of light it emits is related to the stability of its environment. *Pyrodinium* glows only when disturbed or agitated. Strangest of all, nature has built into this tiny bit of life an accurate biological clock. *Pyrodinium* can be agitated into light production only at night. Even when kept in the dark, it "knows" when it is day and when it is night, for it will luminesce only at night.

The unusually bright displays in these bays are caused by *Pyrodinium* populations of about 720,000 individuals per gallon of water. The great wonder is not only why so heavy a dinoflagellate density occurs, but also why the bioluminescence here is so constant, in contrast to the fleeting nature of such displays in the open sea. Why and how this is so is, at present, only partially understood. The remarkable character of the bays has, however, stimulated much scientific interest, and our knowledge of them is steadily growing.

In many ways all three bays are very similar. They are small. Bahía Monsio José, the smallest, has an open water area of only 40 acres, while Caño Hondo, the largest, is but 160 acres in extent. Bahía Fosforescénte is intermediate in size, having an open-water area of about 90 acres. The bays are all fairly shallow, none of them exceeding a depth of 14 feet in any part. They are all cut off from the open sea by a narrow and shallow inlet. And they are all

enclosed by a fringe of mangrove trees. The ability of these bays to concentrate and maintain large populations of *Pyrodinium* is in some way related to these common characteristics.

Some biologists believe that because of their size and shape the bays act as mechanical traps that gather and hold large numbers of dinoflagellates. Because they are shallow and tightly enclosed, the evaporation from their surfaces in this hot and dry region is high. As evaporation proceeds, the surface water becomes increasingly saline and heavier and tends to sink. Less saline water then flows into the bays at their surfaces, while the denser, saltier water leaves near the bottom. *Pyrodinium* is confined to the upper layers of water, and so drifts easily into the bays. Maintaining a position in the uppermost waters, it is not removed by the saline current which leaves the bays near the bottom. The net effect of such a mechanism is to build up a denser population of *Pyrodinium* within the bays than in the adjacent open sea.

This point of view may be helpful in explaining the situation, but it has some obvious difficulties. For one thing, *Pyrodinium* is only one of many species of free-floating organisms confined to the surface layers of the sea. Any such trap mechanism would concentrate them all equally. In relative composition the populations of these organisms differ markedly in the bays from their counterparts in the open sea. Also, there must be something special in the environments of the bays themselves, for even if the trap mechanism is operating, the populations of *Pyrodinium* are sustained over long periods of time. Thus, the trap theory at best only partially explains the mysterious character of the bioluminescent bays.

Of critical importance to an understanding of the bays is the rate at which tides, winds, and currents flush and refill them with fresh sea water. Because of the restricted opening to the sea and a tidal range of only a foot or so, this exchange seems to take place relatively slowly. Thus the bays are sufficiently isolated to permit their waters to develop markedly different characteristics from that of the open sea.

Scientific investigation has shown that not enough food is produced within the bays themselves to support the multitude of organisms that live there. Sources outside the open-water areas of the bays contribute the additional nutrients that keep the populations at their present levels. The chief outside contributor is the border of mangrove trees which tightly encircles each bay. The mangroves grow thicket-like along the black, mucky margins of the bays, their aerial roots firmly planted in the mud and intertwined with each other. These roots form a lattice work which mingles freely with the shallow waters of the bays. Attached to these roots, both in and out of the water, is a fan-

Mangrove roots with attached organisms.

tastic array of plants and animals. The products of these organisms, along with the debris from the mangroves themselves, and perhaps substances washed into the bays from the surrounding land by the infrequent rains, supply the bays with the additional nourishment required to support their populations. This input may also be responsible, directly or indirectly, for the presence of special substances, such as vitamins, that may be important to the ecology of the bays.

Input of organic material from the mangroves, the production of substances within the bays themselves, coupled with such influences as temperature and salinity—all these factors operate on the confined waters of the bays and give them certain characteristics. This water exchanges with the sea at a specific rate that balances with both the input of nutrients and other factors, thereby creating in the three bays a special "broth" that fosters and sustains the growth of large numbers of *Pyrodinium*.

The balance of input and flushing action so favorable to *Pyrodinium* must be delicate, for bioluminescent bays are extremely rare throughout the world. Even slight changes in their shape, size, and entrances, as well as in the mangroves that surround them, could easily bring about the demise of their outstanding displays. Certainly over the long run, as shorelines change and sea levels rise and fall, these remarkable bioluminescent bays are transient and fragile indeed.

Bahía Fosforescénte

Bahía Monsio José

Caño Hondo

Reef life off La Parguera.

The General Environment

The bioluminescent bays lie along the southern edge of the old volcanic upland that forms the mountainous core of Puerto Rico and Vieques Island. This rugged land surface is composed of a complex of volcanic rocks and interbedded sedimentary and marine layers, which are 60 million years old and older. A sliver of younger limestone of Miocene (10 million to 25 million years old) age flanks these older rocks near La Parguera and on Vieques. Like the series of older rocks to its north, this limestone is exposed as a long east-west trending band. It laps against the older rocks on the north and dips beneath the sea to the south. All these rocks—young and old—have weathered and eroded into a generally east-west trending series of parallel ridges and valleys which give the area its washboard landscape. The ridges, some 400 feet in elevation near the coast at La Parguera, reach heights of 4,000 feet less than 15 miles inland. On Vieques the elevations are much more subdued.

The three bays all have a similar relationship to these rocks. Each appears to lie astride a zone of contact between two different rock layers. In each case the contact zone has served as a focus for weathering and erosion, causing the development of a low and irregular trough or valley along its course. Each of the bays lies in a small basin-like depression within one of these troughs.

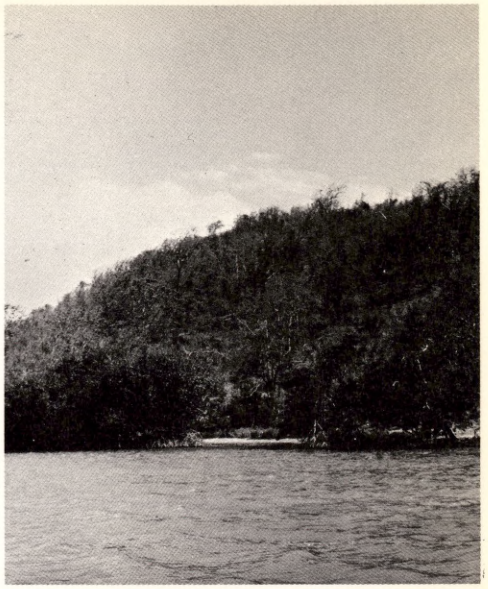
At Bahía Monsio José and at Caño Hondo the headlands enclosing the bays are built of yellowish-white Miocene limestone. At Caño Hondo the limestone forms the rugged mesa-like bluffs at the entrance to the bay, while at Bahía Monsio José the rock is clearly seen on Isla Cueva, which forms the bay's eastern edge. Landward from the bays are older rocks, volcanic on Vieques and an older limestone at Bahía Monsio José.

Bahía Fosforescênte lies in a similar eroded contact zone, with a rugged belt of grayish, silty limestone to seaward and various beds of volcanic debris forming a parallel range of hills to landward. The entrance to the bay is formed by a steep downward fold in the limestone that allows the sea to flow into the basin behind. Thus, in each of the bays the configuration of rock layers, the action of weathering and erosion, and the present level of the sea have worked together to produce small pocket-like basins where the ratio of water exchange with the sea is of the exact value needed to balance other factors and so produce the spectacular displays of bioluminescence.

Puerto Rico and Vieques Island lie in the belt of northeasterly trade winds. For a large part of each year these moisture-laden winds blow steadily across the islands from the east and northeast. As they are forced up over the high central mountains of Puerto Rico, they are cooled and their moisture is

squeezed out. When the winds descend the opposite slopes, however, they are warmed and dried. Thus, while abundant rainfall occurs on the island's windward slopes, the leeward slopes fall within a profound rain shadow. At La Parguera rainfall measures only about 30 inches a year, while but a scant 15 miles away in the central mountains well over 100 inches fall.

About half of La Parguera's rain falls from April to July and most of the rest from September to November. In this tropical region where temperatures outside the 70° to 90° F. range seldom occur, evaporation is high. The scant rainfall and prolonged droughts produce decidedly arid conditions. On Vieques Island there is no rain shadow, but conditions are nevertheless quite similar. Aridity prevails because the island's hills do not rise high enough to force much water from the winds.



A dry hillside bordering Bahía Fosforescénte.

No permanent streams exist on Vieques Island, nor for that matter along the entire La Parguera section of the Puerto Rican coast. There is no regular discharge of fresh water into the adjacent sea. The small thorn and scrub-covered hills provide only small drainage areas to the sea, so that even during heavy rains, the input of fresh water into the sea is small. Offshore marine conditions are, therefore, quite stable. Temperatures vary little, salinity is high and constant, and the influx of silt into the clear offshore waters is low and usually absent. On the shallow limestone shelf offshore from La Parguera these stable conditions have favored the growth of corals and other marine life.

The stability of these offshore waters may be an important factor in the development of the bioluminescent bays. But we must be careful not to attribute too much to this stability, as other factors may be much more important. For example, in one of the few other bioluminescent bays presently known—the one at Falmouth Harbor, Jamaica—a large volume of fresh water regularly discharges into the bay itself. Though this water does not readily mix with the saline waters in which the bioluminescence occurs, the development of spectacular bioluminescence is certainly not prevented by the proximity of a regular discharge of fresh water.

The Dry Hillsides

A thin veneer of rocky soil clothes the limestone hills about La Parguera. Little of the scant rainfall is retained by this soil, and the condition of drought on these slopes is severe. They support a sparse growth of plants, all of which are adapted to the prevailing dryness. Characteristically, the growth is an open stand of trees rarely exceeding 45 feet in height, and usually much shorter, that rises out of a dense bramble of thorny shrubs. Herbaceous plants are few.

For the greater part of the year the hillsides stand sere and brown against the drought. Many of the trees and shrubs resist the dryness by such structural adaptations as thick and leathery leaves. Others face the dry season by dropping their leaves and entering a period of dormancy, while still others, their foliage brown and curled, barely manage to survive from one infrequent rain to the next.

The commonest trees of these dry hillsides are the redbarked gumbo-limbo or almacígo *(Bursera simaruba),* úcar *(Bucida buceras),* a bitterwood *(Trichilia hirta),* and the prickly-ash *(Zanthoxylum monophyllum).* Here and there the century plant, with rosettes of swordlike leaves, dots the scene. Large mat-like clumps of prickly-pear, numerous ruddy-colored barrel cacti rooted on the rocky ledges, and the occasional 6- to 10-foot spire of a columnar cactus give these thicket-woodlands a strange, desert-like flavor. High in the branches of the trees grow fleshy-leaved air plants and numerous tufts of string-like growth resembling Spanish moss, and the dark form of a massive termites' nest can sometimes be seen outlined against the sky.

On Vieques Island, too, the hills adjacent to Caño Hondo are dominated by an arid open woodland. In the few spots not severely grazed by cattle, the vegetation is similar to that found about La Parguera. For the most part, however, the scene here is that of an open savannah dominated by thorny acacia *(Acacia macracantha* and *Acacia riparia)* and maran *(Croton asteroites).*

Cattle and goats graze everywhere on these hills. But the most conspicuous elements of the native wildlife are a rich and interesting bird fauna and a surprisingly large population of rock lizards.

Mangrove backwaters at Bahía Fosforescênte.

The Mangrove Fringe

The mainland adjacent to La Parguera is protected from storm waves by the coral reefs and islands which lie offshore. The intertidal zone along these shores supports a flourishing mangrove thicket. Where the coastal hills plunge directly down to the sea, the mangroves form a narrow ribbon between the sea and the arid hillsides. Only in places where the coast is quite flat does this lush growth cover any sizeable area. Thus, the mangroves which fringe the coast and cover many of the islands and reef flats about La Parguera vary from a narrow strip scarcely 10 feet wide to broad and expansive tracts over 1/2 mile across. In these larger tracts the mangroves are truly transitional between land and sea. They form dense thickets of trees rooted in mud and continually washed by the ebb and flow of tides. Tortuous canals overhung by a canopy of dark green twist through the wild tangle of roots and branches, and ponds and mud flats appear here and there amid jungle-like growth. It is difficult to imagine a contrast more profound than between these dark, dank mangrove

swamps and the brown, arid woodlands of the nearby hillsides.

On Vieques Island the coast adjacent to Caño Hondo is fully exposed to the force of the open sea. The coast has been battered into rugged sea cliffs, rocky islets, and occasional broad strands of gleaming sand. Here mangroves are confined to the sheltered intertidal waters of Caño Hondo itself.

The mangrove fringe is dominated by the red mangrove or mangle colorado *(Rhizophora mangle),* whose tangle of arching prop roots gives to the forest much of its grotesque appearance. The black mangrove or mangle prieto *(Avicennia nitida),* although less abundant than the red, is nevertheless common on the wetter sites. It is easily recognized by the myriads of pencil-like breathing roots that rise through the mud beneath it. In the drier sections two other species of mangrove grow in mud that is wetted only by the very highest of tides. These are white mangrove or mangle blanco *(Laguncularia racemosa)* and the buttonwood or mangle baton *(Conocarpus erectus).*

In areas dominated by the red and black mangroves the floor of the forest is wet, black mud. Only the seedlings of the mangroves themselves grow up through the tangle of the roots and branches of their parents. In the drier parts of the forest, ferns and grasses are able to grow beneath the mangroves. The mangrove world is dark and quiet, a somber place of twisted forms. Its shadowy half-light seems strangely eternal.

The tangle of arching roots and drooping branches harbors a fascinating array of life. Flashes of color from a yellow warbler or a bananaquit as it flits from branch to branch startles by its contrast to the gloom of the forest. Numerous crabs climb within the jungle-like growth, retreating to burrows in the mud when frightened. Smaller fiddler crabs scavenge the surface beneath the trees. Large brown snails move up and down with the tides, always staying just above the water's edge. Much smaller ruddy-colored snails, which so nearly match the color of the mangrove roots that they are difficult to see, follow a similar pattern of movement. Roaches and crickets and many spiders flourish here, as do a large number of anole lizards which hunt among the branches and roots above the tidal floor.

Within the water the lattice work of roots supports many plants and animals that feed on the tiny bits of life with which the tidal surge continually bathes them. Algae, several kinds of oysters, barnacles, brightly-colored sponges, anemones, tunicates, and polychaete worms—all live attached to this root network. It is a world of mud-colored water, grayish-brown indistinct forms, splashed here and there with unbelievable bits of orange and red and purple. And it is a passive world, animated only now and then by the sudden lunge of a predatory fish or the foraging of a decorator crab.

Reef life off La Parguera.

The salinas behind Bahía Fosforescénte.

The vital role that this root community plays in the organic balance of enclosed bays has already been mentioned. Indications are that it is essential to the capacity of some of these bays to support spectacular bioluminescent displays. Many of the attached forms, when they die, join the debris from the mangroves themselves and fall into the sluggish tidal waters. There the debris is attacked by decay organisms and reduced to substances that greatly increase the ability of these waters to support life. Within the sheltered backwaters of some of these mangrove bays—such as Bahía Fosforescénte itself—the water is dark brown to muddy gray with the organic contribution from the mangroves and the life on their roots.

Offshore from La Parguera those shallow reef flats that enjoy some protection from wave action are able to support mangroves on the broken coral of their surfaces. Red mangrove is the dominant growth here. Associated plants and animals are a mixture of the usual species found with mangroves and those that normally occur on reef flats.

Within the tangle of mangrove roots and branches, debris of all sorts is trapped and held. Water can only move slowly through this restricted network and is, therefore, unable to pick up material off the mangrove floor or to hold any but the finest debris in suspension as it moves through. As a result the mangrove floor is slowly built up and the mangroves are able to advance seaward. Hurricanes and other violent storms periodically check this advance, but there are many places along these shores where the mangrove community has made considerable progress into the sea.

The Salt Flats

Well back into the mangrove fringe, where the washing of the tides is infrequent, the region's high rate of evaporation conspires with the voluminous transpiration of the mangroves to produce environments dominated by salt. In the backwater mangrove areas are occasional small ponds, which only the highest tides fill. They become so salty that they support only a restricted life, mostly brine fly larvae and the minute brine shrimp. As these ponds dry up, their retreating margins are marked by windrows of millions upon millions of tiny brown brine shrimp eggs.

The highest parts of the intertidal zone are wetted by only a few tides during the year. Here the sea comes too infrequently to support a lush mangrove growth, and evaporation has left too much salt in the soil to allow the normal dry hillside vegetation to grow. Instead a specialized group of salt-tolerant plants is often found. This growth is usually dominated by the fleshy swollen stems and leaves of the yellowish-green saltwort *(Batis maritima)* and the

darker green or sometimes reddish sea purslane *(Sesuvium portulacastrum)*. These plants grow in low, thick mats of one species or the other, occasionally enclosing a depauperate mangrove or a small salt-resistant shrub. In many places, however, the concentration of salt in the soil is so high that even these plants are unable to grow, and the area is barren and lifeless. The salt crystals on these whitened flats glisten and sparkle brightly in the sunlight.

For many years the inhabitants of these arid coasts have developed the natural salt flats for the commercial production of salt. By simple changes, many of these flats have been converted into salinas, where salt is extracted from sea-water by evaporation. In most cases, some of the mangrove has been cut to widen the natural flat and a small canal cut from the flat to the sea. Water is turned into the flat, now deepened somewhat and defined by low dikes. Evaporation proceeds until only a fine cake of salt remains. This is scraped off, a new charge of water allowed to flow in through the canal, and the process repeated. This simple operation is conducted in the same manner as early man used in other parts of the world.

The natural flats behind Bahía Fosforescénte and Bahía Monsio José have been replaced by small salinas, but the mangroves of Caño Hondo are still backed by a natural flat. As far as is known these salt operations have had little or no effect on the ability of these bays to produce bioluminescent displays.

Islets and fringing reefs offshore from La Parguera.

The Reefs

A shelf of limestone rock juts out into the Caribbean from the La Parguera coast. This broad shelf, until it drops precipitously to oceanic depths some 6 miles offshore, lies under only 30 to 90 feet of water. The shoreward half is irregularly scattered with coral reefs. Some reefs are deep, others are barely submerged, while still others emerge above the sea and are spotted with small growths of mangrove.

Across these reefs wash the warm, clear waters of the open sea. The salinity of the water is constant, for along this dry coast the sea is seldom diluted with fresh-water runoff from the land. Because no rivers discharge in this area, the sea is never clouded with silt and sediment. In every respect conditions are ideal for the growth and development of corals and associated organisms. The marine life is, in fact, abundant and rich in variety. What is more, the reef life thrives close to shore and is easy to reach. The outer reefs break the force of the sea and protect many inner reefs. Contrary to so many reef areas, the La Parguera reefs can almost always be safely visited in a small boat.

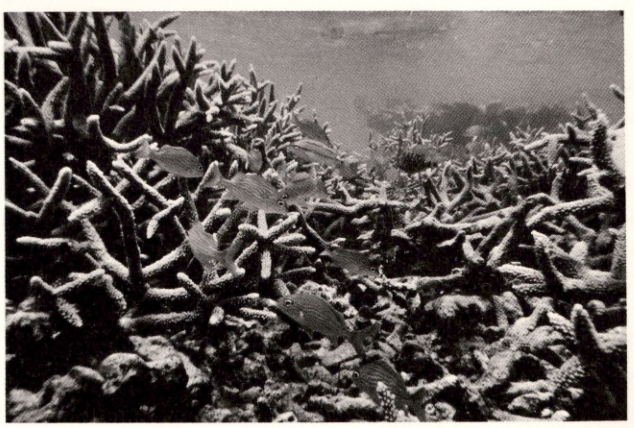
Massive corals compose the seaward face of the outer reefs, which absorb the

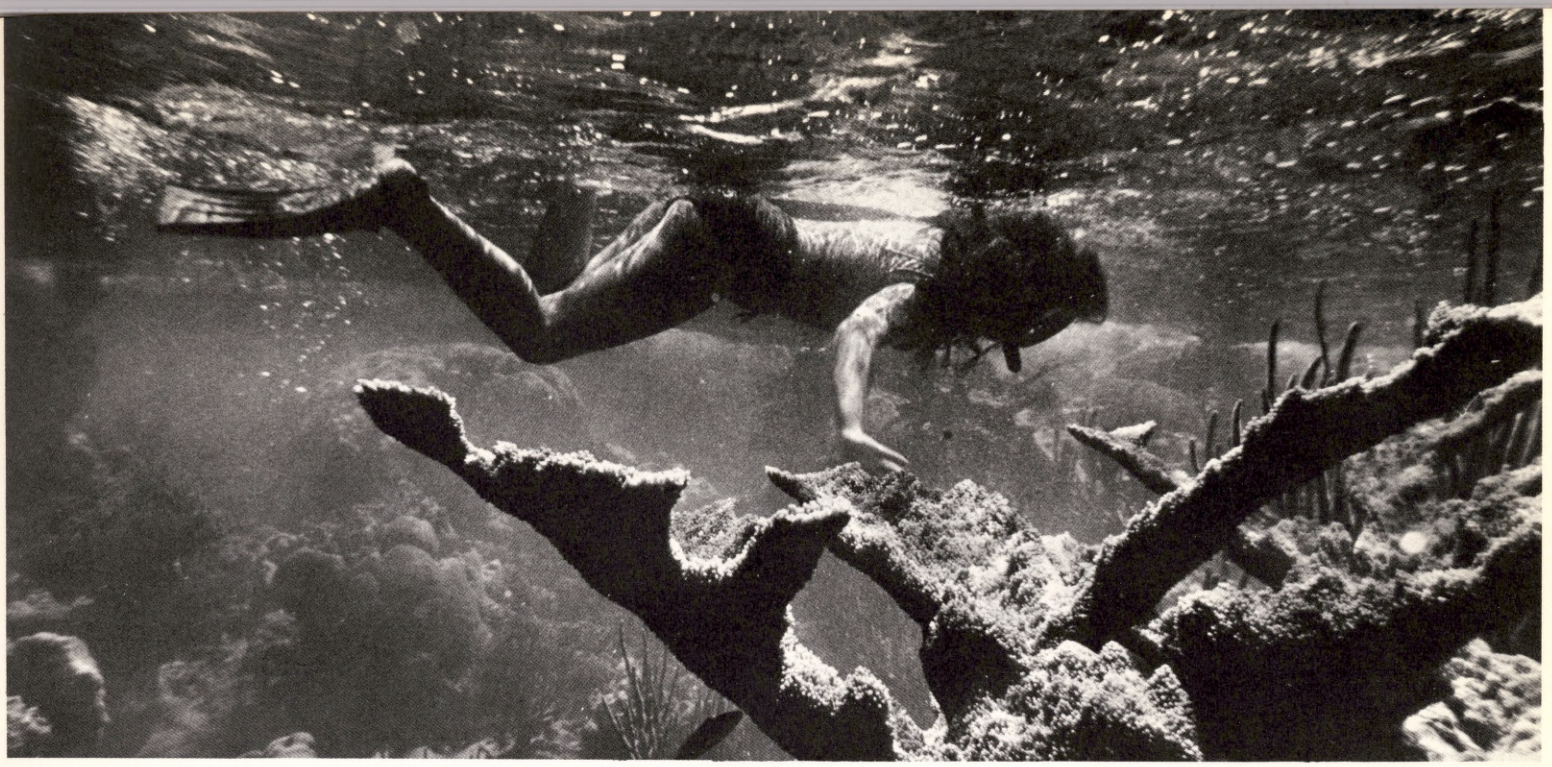
full impact of the waves. Here a spectacular underwater scenery is formed by the sturdy golden brown arms of the elk-horn coral as they reach into the waves. Green, gray, and brown boulder-like masses of the coral *Montastrea* also help to shape the reef front into a series of spurs, or buttresses, that project out into deeper water. The spurs are separated from each other by narrow canyon-like grooves, often with perpendicular or overhanging walls.

At the base of this face lies a dense violet carpet of *Porites* coral, and the submarine landscape is much enlivened by the swaying, brightly colored sea fans, sea feathers, and sea whips. The nooks and crannies within the corals shelter crabs, lobsters, mollusks, and a great and colorful variety of fishes.

The outer face of the reef appears to advance slowly seaward with time. Large coral fragments broken off in heavy storms fall to the base of the slope. Here they accumulate and are cemented into a solid, coherent mass by the growth of calcareous algae and other corals. Thus stabilized, they support further coral advance seaward.

Storms wash the finer fragments of broken coral up over the edge of the reef where they accumulate to form a rough pavement of broken rock on the reef flat. The flat, which lies under but a few feet of water, is the consequence of the reef front's seaward growth. It is covered with a green carpet of the anemone *Zoanthus,* along with brownish and grayish patches of a few mat-like coral species. The holes and crevices of the flat conceal a fascinating variety of marine creatures.





Snorkling over the La Parguera reefs.

Behind the reef flats the water deepens and is usually calm and placid. The bottom is fine coral sand and calcareous mud, the fine debris of the storm-battered reef face. These lagoonal areas are dominated by dense meadows of turtle grass that alternate with areas of barren sand and, in the shallower waters, with an occasional stand of the slender manatee grass. The grass beds harbor isolated colonies of coral, sponges, crabs, snails, sea cucumbers, starfish, and an abundance of urchins.

Small fringing reefs extend out from the shallow mainland shore in many places and surround several of the off-shore islands. Like the reef flats, they are shallow and can be easily explored by wading. They vary greatly in character, but share many of the characteristics of the reef flats. Most often, they are built of a complex intertwining mat of green finger-like branches of *Porites* coral. Within this coral matrix are sponges, crabs, mantis shrimp, sea cucumbers, brittle stars, anemones, and a host of other organisms.

It is possible here only to hint at the great abundance and richness of life in these extensive reef and turtle grass communities. All the variety and splendor of the tropical seas are here to see. Because of the configuration of the reefs and shores, it is more easily and safely seen here than in most other places. The reefs of La Parguera join its remarkable bioluminescent bays to create an outstanding marine area, one unrivaled anywhere in the world.

Off Vieques Island near Caño Hondo, the land dips steeply into the sea. Coral reef development is limited to a few small fringing reefs scattered here and there along the rocky shores.

The village of La Parguera.

The Immediate Danger

The bioluminescent bays are delicate and fragile systems. They depend upon an input of organic material that is partly offset by an exchange of water with the adjacent sea. Only a certain ratio of input to exchange is capable of supporting bioluminescent displays, and the rarity of such bays throughout the world testifies to the extremely narrow range of this ratio. Even slight environmental changes could throw the necessary balance sufficiently off to destroy the capacity of these bays to support bioluminescence. The bays are in danger of such destruction, for present controls are no longer effective to guard against arbitrary alterations to the sustaining environments.

One of the most crucial factors in the well-being of these bays is the maintenance of the manner and rate with which their water exchanges with that of the outside sea. Each bay has a particular flushing rate that balances the organic input from its mangrove fringe to provide the nutrient "broth" capable of sustaining a high population of *Pyrodinium*. Should this ratio of water exchange be altered, the bioluminescence will disappear.

Evidence for this is clear. Many years ago a bioluminescent bay, called Fire Lake, was located near Nassau on New Providence Island in the Bahamas. In character it was similar to the present Puerto Rican bays. When the narrow entrance was dredged to permit larger boats to enter the shallow bay, the bioluminescence immediately disappeared and has not returned.

A similar situation occurs in the La Parguera area. Historically, Bahía Monsio José has supported brilliant bioluminescence, and while it was apparently never as constant as Bahía Fosforescénte, it nevertheless was capable of supporting remarkable displays. Just a few years ago, however, the National Institutes of Health established a research project on Isla Cueva, which forms the eastern side of Bahía Monsio José. The project required the confinement of monkeys on Isla Cueva and to assure that they did not escape, a barrier was constructed across the mangrove neck connecting the island to the mainland. A swath was cleared through the mangrove, a canal cut through the muck from the bay to the sea, and an electric fence erected along the canal. Although the barrier keeps the monkeys on Isla Cueva, it has had an adverse influence on the bioluminescence in the bay. Local residents say that since construction of the canal, the brilliance of bioluminescence has dropped markedly. Bioluminescence still occurs and is noteworthy, but is significantly less bright than in Bahía Fosforescénte and Caño Hondo. The barrier canal has, presumably, altered the bay's exchange ratio, thereby reducing its ability to sustain *Pyrodinium*.

The canal that joins Bahía Monsio José with the sea (foreground).

The input of a precise quantity of organic material into the bays is also critical to their ability to support bioluminescence. Should the mangroves surrounding one of these bays be cleared, most of the organic input into the bay would cease. The character of the bay's water would change, and bioluminescence would undoubtedly be seriously affected. Similarly, an increase in the organic input into a bay would also alter the balance. Such input could easily come, for example, from the discharge or seepage of sewage into either the bays or their adjacent waters.

The key to the survival of the bioluminescent bays, then, is the perpetuation of the delicate balance between the exchange of water with the sea and the input of organic material from the mangroves. Even slight changes in this balance could be catastrophic to the maintenance of their extraordinary properties. New and effective controls are urgently needed to prevent arbitrary actions and negative environmental influences from destroying the equilibrium upon which the bays depend. All about them waters are being dredged, canals built, mangroves cut, and waters polluted. With each passing year these seem to occur at an accelerating pace. It is remarkable that the bioluminescent bays even survive today. Forces are loose in the environment that could literally at any time bring about their demise. Unless the bays are protected from such forces, and soon, the future is not bright.

A Longer Look

By their very nature these marvelous bays and their colorful surroundings have drawn people to them. They are delightful places to visit and serve as the hub for a good deal of tourist and recreational activity. Though such activity about the bays and reefs is understandable and economically desirable, its uncontrolled growth will eventually spell the demise of the very features that have spurred it in the first place.

Threats to the well-being of the bioluminescent bays are, therefore, not all immediate or of large scale. Slow and gradual changes in the environment are occurring that will produce no sudden result but, projected over the years, are just as capable of destroying the bays as are the dredging of channels or cutting of mangroves.

As word of the strange biolumiscent bays and the accessibility and beauty of the coral reefs has spread, La Parguera has expanded as a tourist center. Several small hotels have opened, and resort homes and cottages are proliferating along the mangrove shore. This development has proceeded rapidly during the past few years and, unless checked in time by new and more effective controls, will have serious environmental consequences.

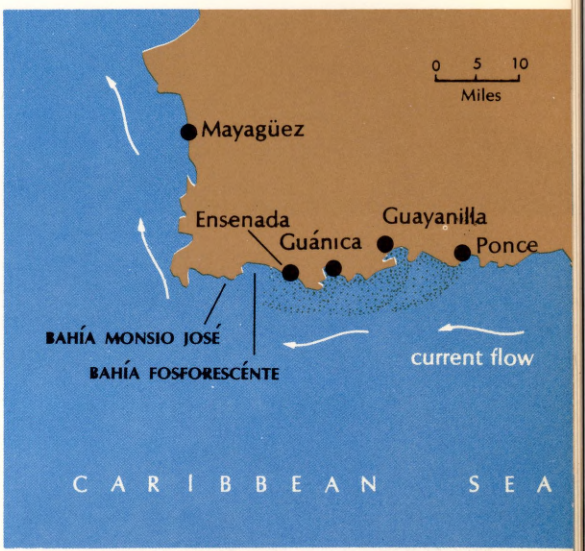
The bioluminescence of Caño Hondo on the presently remote Vieques Island is not well known and a comparable development has not yet begun here. Plans are in the making to spur that island's lagging economy, and the Commonwealth is in a much better position to prevent the problems of La Parguera from being duplicated there.

Of greatest concern in the La Parguera area is the mushrooming growth of resort homes. Generally these take the form of houseboats or dock-type houses built out over the water. Because there are no sewage treatment facilities for the village, a constantly increasing amount of raw sewage is being released into the sea. The effect of this pollution is plainly evident in the altered ecology of the mangrove-lined waterways adjacent to La Parguera. The pollution has also created a human-health problem.

An accelerated construction program for new sewage facilities has been removing health hazards in many sections of the south coast, but the introduction of a nutrient-rich effluent into the sea is not without biological consequences. The westerly currents that parallel Puerto Rico's entire southern coast carry the nutrient across the mouth of Bahía Fosforescénte, just as the pollutants of La Parguera are wafted toward Bahía Monsio José. At present, there is no evidence that the amounts of organic matter and nutrients released along these shores have produced adverse effects on the bays or the reef communities, but the possibility of cumulative biological effects cannot be discredited. While the bioluminescent decline of Bahía Monsio José is a direct result of the building of the canal, the heavy pollution moving toward the bay from La Parguera may be aggravating the situation. In any case, it is clear that if the present trends continue, pollution will increase and one day noticeably affect the bay and reef communities. How close we are to such a point is not known, but the delicate balance of the bays suggests that such a state may not be far off.

But the danger is not limited to sewage and associated nutrients from local communities. Pollution is a much broader and more complex problem, and it involves Puerto Rico's entire southern coast. Much of the island's major industry is located along this coast. Strong westerly flowing currents carry industrial pollution along the shore toward La Parguera. If voluminous enough, it will be felt there.

A scant 7 miles east of La Parguera is the seriously polluted Bahía de Guánica. It receives the discharge from the Caribe Nitrogen Corporation plant located along its shore, as well as the wastes from the Ensenada Sugar Central and the public sewage treatment plant of the Ensenada-Guánica urban area. Twelve miles further east on the Bahía de Guayanilla is Puerto Rico's major petro-



Pollution introduced into the sea east of the bioluminescent bays tends to be carried toward them by prevailing ocean currents.

chemical complex and, still further east, the developing complex near Guayama.

These industrial areas are sources of serious pollution now, and current plans for expansion of existing facilities, as well as addition of new industries, can only increase the magnitude of the problem. Commonwealth anti-pollution efforts must be forceful and dramatic to turn the tide in this regard.

It is sufficient to note that the sources of pollution along this coast are many and will continue to grow. Their present effects are not well known or understood, and unlike the obvious deterioration of swimming beaches and other recreational features of the shore, the threshold of destruction for many marine resources is obscure. What is certain is that any further growth of pollution along the island's southern coast threatens the bioluminescent bays and coral reefs. It is important to understand that these outstanding features cannot be perpetuated, regardless of how secure their local environments are, if the broader problem of pollution along the south coast is ignored. This will require continued research and significantly more public investment than the Commonwealth has been able to afford so far.

"Atmosphere" is a significant factor in the enjoyment of the bioluminescent bays. The "burning of the sea" is a strange phenomenon, and the emotional impact it has upon the viewer is strengthened by the darkness, silence, and apparent remoteness of these bays. These factors are now seriously compromised by the increasing numbers of people using the bays and their surroundings. In Bahía Fosforescénte, by far the most heavily used of the bioluminescent bays, it is now difficult to be aboard the only boat in the bay. There are often two or more boats in the bay at any one time, a circumstance which greatly reduces the feeling of isolation that so heightens the impact of viewing these strange displays. Then, too, the voices of people on the shore and the noises of nearby automobiles often drift out into the bay. Lights from nearby houses shine into the bay, their glare on the water's surface obscuring the bioluminescence and making it less impressive than it would otherwise be.

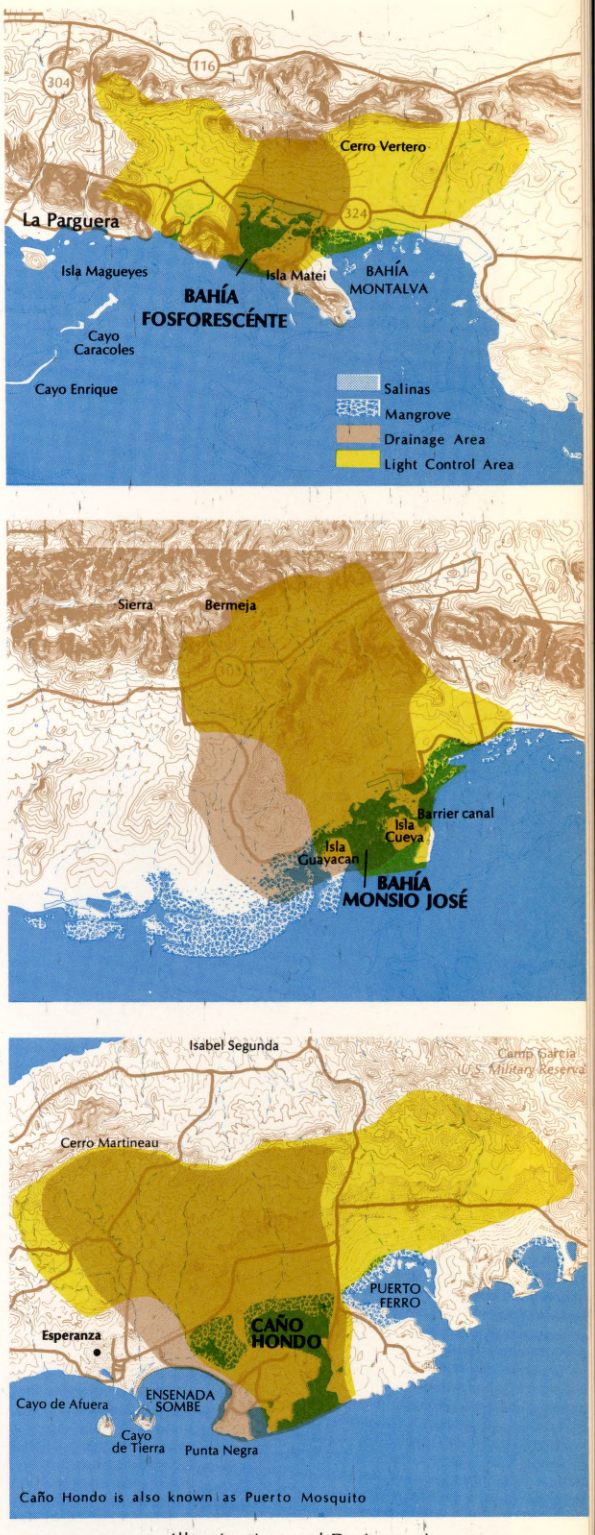
The role played by fishes in the overall biological balance of the bays, as well as their role in the sustenance of bioluminescence, is not known. Their esthetic value, however, is unquestionably great. The fiery streaks they make darting through the water is one of the most spectacular elements of the bioluminescent displays. That local fishermen work these waters threatens not only the biological stability of the bays but also their bioluminescent beauty.

Small boats are almost continually seen among the coral islands and reefs

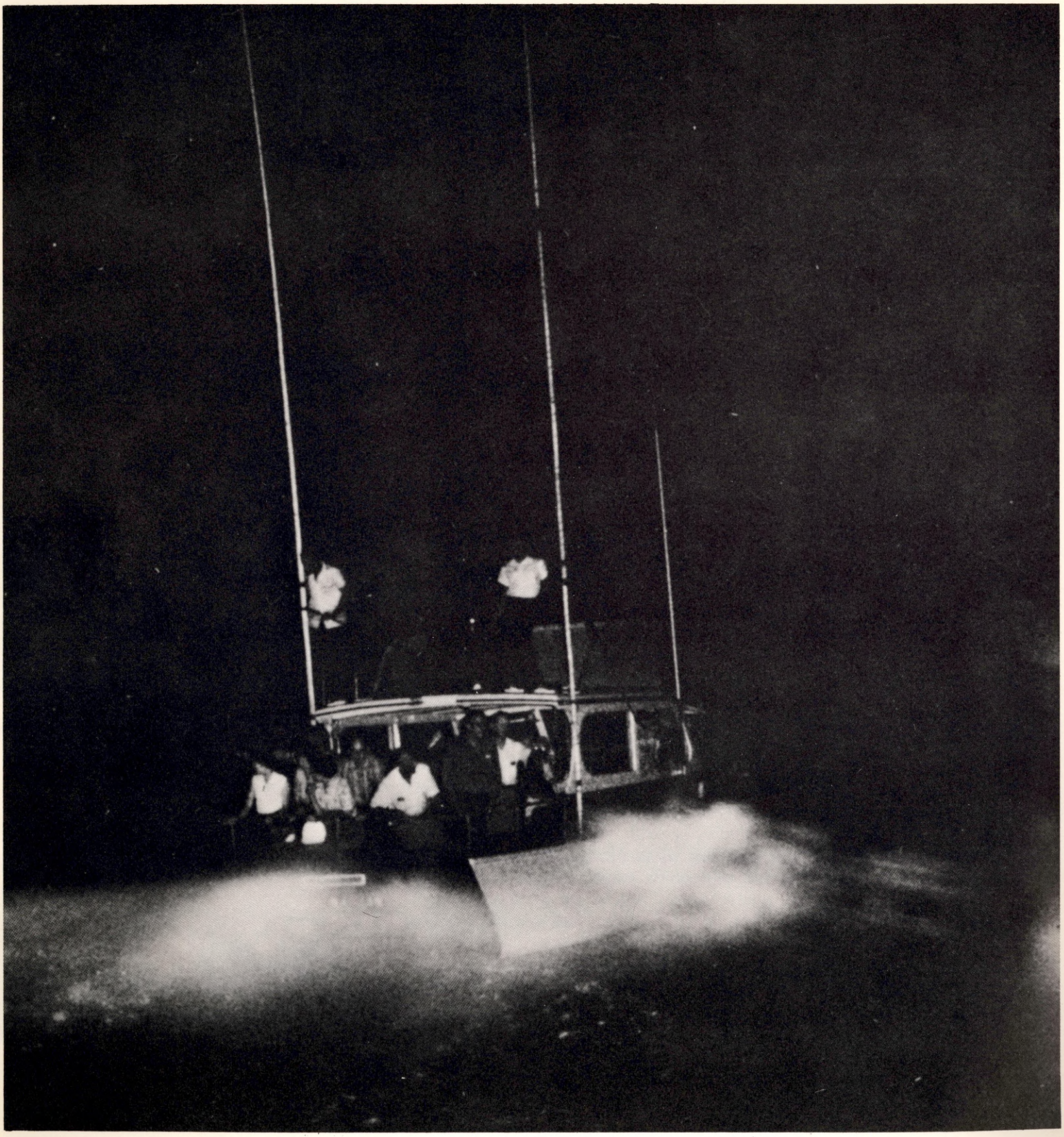
offshore from La Parguera. Like the bioluminescent bays, this picturesque marine resource is beginning to show the effects of heavy use. Resort cottages have appeared here and there on some of the islands, and on Cayo Caracoles an overnight camp with primitive shelters has been developed. Many of the fringing reefs have become depauperized through the activities of countless people wandering across their shallows and removing the most interesting organisms.

Small-scale commercial fishing—the traditional occupation of La Parguera—has over the years kept many of the fishes and associated reef species relatively scarce. In addition, amateur collectors continue to remove large quantities of corals and other animals each year.

The obvious conclusion to be drawn is that the bioluminescent bays and their adjacent marine environments are seriously threatened. Immediate controls and long-range protection are needed if these outstanding resources are to be saved from gradual deterioration and eventual elimination.



Illumination and Drainage Areas



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A tour boat stirs the waters of Bahía Fosforescénte to luminescence.

A Philosophy for Preservation and Use

If current trends continue, it is inevitable that Puerto Rico's bioluminescent bays will eventually succumb to the forces of environmental deterioration. Such forces are now well in progress all about them, and how long such fragile features will be able to survive is not really known. A good guess is not too long. The loss of these rare and remarkable natural features to the world would be truly tragic. But their loss to Puerto Rico would be a double catastrophe, for these extraordinary natural displays could be the hub of an impressive tourist development and a real boon to the island's economy.

The following plans, if implemented, will assure the perpetuation of the bioluminescent bays. In formulating these plans several basic philosophical positions were adopted:

(1) The bioluminescent bays should be preserved so as to maintain the intense bioluminescence they display. Public use of these bays should allow people to see and appreciate the bioluminescence to best advantage, but such use must be compatible with long-range preservation. All other potential uses of the bays should be subordinate to these goals.

(2) Preservation of the bays requires the control of areas adjacent to the bays. Only by such control can the environmental factors sustaining the bays be adequately maintained.

By adding such areas to the plans, not only are sustaining environments protected, but the opportunity for a variety of daytime visitor activities is also provided. By including the beautiful beach at Ensenada Sombe in the proposal for Caño Hondo, for example, swimming, picnicking, and similar pursuits will be available to people visiting the bioluminescent bay at night.

Similarly, the coral reef communities of La Parguera are included in the proposals for that area. They provide an excellent focus for daytime visitor activity to complement the night use made of the bioluminescent bays. These reefs and associated marine environments are outstanding natural resources and worthy of preservation in their own right. Only such public use should be made of them as is compatible with their preservation in the long run.

(3) Active recreational pursuits, such as swimming, motor boating, and water skiing, should not be allowed to become dominant activities within the La Parguera area. If too extensive, they would conflict seriously with the basic need to preserve the environment for its educational and

inspirational values. Such activities should be concentrated outside the La Parguera area.

To the west of La Parguera, near Cabo Rojo, natural circumstances are more favorable for active recreational pursuits. We urge that this area be developed for such uses. Thus, the growing demand for active recreation would be met, while the outstanding natural features of La Parguera would be preserved. It is difficult to imagine a more ideal arrangement for the development of an outstanding tourist area.

Given these basic ideas for preservation and public use of the bioluminescent bays and their surroundings, detailed recommendations follow logically.

Preservation of the Bioluminescent Bays

Our ecological knowledge of the bioluminescent bays is meager. We have only a rudimentary understanding of the factors which support and sustain them. Further research is urgently needed into the nature of bioluminescence in the bays and the factors which promote it. Meanwhile, the most satisfactory approach to preservation would be to maintain as nearly as possible natural conditions in the bays. Failing that, we should at least maintain the environmental situation as we now find it. The following points are strongly recommended:

(1) The drainage basins of the three bioluminescent bays, Bahía Fosforescénte, Bahía Monsio José, and Caño Hondo, should be placed under effective public control, either through acquisition or firm zoning controls, though public ownership would be the most effective method. Activities within the basins must be controlled to prevent further damage to the mangrove fringe and to assure that pollution from the land does not enter the bays and threaten their ecological stability. At an absolute minimum the areas immediately adjacent to the bays should be purchased and the remainder of each basin zoned to hold the present land use.

Ideally, the reversion of the drainage areas to their natural condition would be desirable. The possibility of environmental pollution from the land would be minimized and an esthetically pleasant backdrop created for the bays. This would also simplify the control of human activity within the basins. If private use of the land within the drainage continues, it will be a formidable task to impose the necessary use and access restrictions.

(2) As much as possible of the ocean frontage from Punta Pitahaya eastward to the first area of major coastal pollution at Bahía de Guánica

should be secured. Specifically, this requires public ownership or firm zoning control for a strip of land from Punta Pitahaya to Punta Brea at the mouth of Bahía de Guánica. This would create the largest possible buffer for the La Parguera bays against pollution borne by westward currents. It would also prevent new sources of pollution from developing nearer to the bays and would provide an appropriate setting for the reef environments offshore.

On Vieques Island the shoreline up-current from Caño Hondo is presently under military control, and effective pollution control can probably be maintained there through cooperative agreements between the Commonwealth and the military.

It cannot be emphasized too strongly that these measures will, at best,

Cabo Rojo juts seaward like a giant claw. The entire area has excellent recreational potential.

The broad, sandy beach at Ensenada Sombe on Vieques.

offer only a degree of protection from up-current pollution. If that pollution continues to grow, the buffer will not be effective. Preservation of the bioluminescent bays ultimately depends upon establishing effective pollution control measures along the entire southern coast of Puerto Rico.

(3) The addition of sewage or sewage nutrients into the marine environments at the villages of La Parguera and Salinas Providencia should be reduced to the maximum extent consistent with practical sewage-treatment technology. This requires the removal of all houseboats and waterside cottages without adequate sanitation and the construction of suitable sewage-treatment facilities for both villages. These facilities should be designed to discharge as little nutrients into the sea as possible.

(4) In order to restore and maintain the darkness necessary to full enjoyment of the bioluminescent displays and to minimize distracting glare on the water surface, it is urged that an attempt be made to limit the number of land-based lights that can be seen from boats within the bays. Removal of unnecessary exposed lights on adjacent hills and slopes would accomplish much, as would the screening and shading of other lights.

(5) The presence of fishes within the bays adds greatly to the visual effectiveness of the bioluminescent displays. Also, the role of fishes in maintaining the ecological balance of these waters may be significant. We therefore urge that the natural levels of fish population be assured by prohibiting all fishing within the bioluminescent bays.

(6) An attempt should be made to restore the bioluminescent displays formerly found in Bahía Monsio José. This will require the repair of damages done on Isla Cueva by the National Institutes of Health program on tropical diseases. Repairs should include the refilling of the canal and the replanting of mangroves in the swath cleared for the electric barrier fence. Perhaps a suitable confining device for the monkeys kept on Isla Cueva can be devised that will not damage the bioluminescence of the adjacent bay. If not, the National Institutes of Health program should be located elsewhere and not continue to jeopardize so rare and unusual a resource.

(7) Tour boats using the bays should not be a source of either physical or esthetic pollution. Exclusive use of electrically powered boats would remove the threat of direct pollution to the waters of the bays. Their use would also heighten the dramatic effect of viewing the bioluminescence by reducing noises to a minimum. Controls are also needed to insure that no more than one tour boat at a time uses any of the bays.

(8) The existing research effort should be accelerated. It is vital to achieve a better understanding of the resource and the factors which sustain it. A program of environmental monitoring is also needed to detect at an early stage adverse conditions or threats to the environment from outside the area. Specifically, this should be a long-range, continuing program that would include:

(a) quantitative measurement of the bioluminescent displays in each of the bays;
(b) quantitative measurement of the organic content of offshore waters;
(c) quantitative measurement of the turbidity of offshore waters;
(d) qualitative study of the nutrients in the offshore waters; and
(e) quantitative study of the plankton in and near the bays.

In order to provide a standard for such monitoring, careful measurement of present conditions is needed.

Preservation of the La Parguera Reefs

With respect to the coral reefs and associated marine environments offshore from La Parguera, we recommend the following:

(1) To preserve the outstanding natural features of the marine shelf offshore from La Parguera, a protective reserve should be established around the coral reefs and associated marine communities. Activities within this reserve should be controlled to insure that these resources will be perpetuated intact. The reserve would also function as a buffer for the bioluminescent bays against marine pollution.

(2) The collecting of marine organisms, including fishes, from the reef tracts should be prohibited. The primary attraction of these areas is their wealth and abundance of living forms. Fishing and other forms of collecting are not compatible with the preservation of these resources for the sustained enjoyment and enlightenment of the people.

The Commonwealth could establish specific areas in which fishing would be permitted, provided it did not reduce the opportunity for visitors to see the natural abundance of fishes in either the bays or the reef tracts.

(3) Boating regulations that will eliminate damage to the reefs and danger to people attempting to view the reefs should be adopted.

(4) All existing development should be removed from the offshore keys to maintain the natural appearance of the area.

(5) Zoning controls for the villages of La Parguera and Salinas Providencia should be implemented to insure that these towns do not become serious intrusions upon the natural scene.

(6) We assume that the marine laboratory on Isla Magueyes will continue to operate. Scientific research (including collecting) within the preserved area should continue, provided that it does not in any way adversely affect the perpetuation of the bioluminescent bays, coral reefs, or associated environments. The results of this research will supply the information necessary for applying sound preservation techniques as well as nurturing a program of public interpretation and education.

(7) The Commonwealth organization or agency charged with responsibility for maintaining this reserve must have effective enforcement authority to implement the above recommendations and to pursue and prosecute violators.

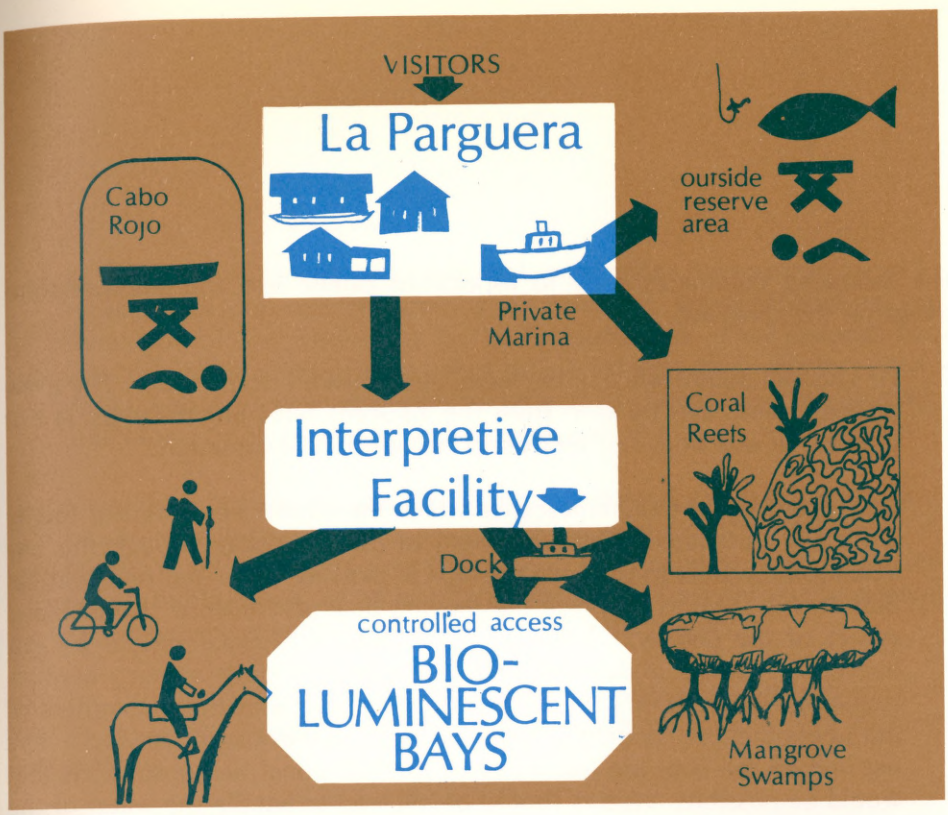
Wading on the offshore reefs near La Parguera.

Patterns of Visitor Use

The most significant value of the bioluminescent bays and their environs lies in the wonder and awe that they inspire in the human mind. This is sufficient reason for their preservation, without citing the considerable value they have for scientific investigations. It is for this that they should be preserved. The measures proposed will maintain the physical qualities which give rise to these features as well as the esthetic environment necessary to their enjoyment. But a visitor's appreciation can be expanded if he understands the things he sees. Any effective administration of the bays must, therefore, seek to heighten visitor awareness through a program of public enlightenment and interpretation.

Exhibits, talks by trained personnel, guided boat trips, conducted tours, audio-visual presentations, and publications are among the techniques that should be used in developing an interpretive program for the area. Such a program, of course, requires the establishment of a competent staff and the regular allocation of funds to support its activities. Some revenues needed to sustain these activities could be derived from tour charges and the sale of informative literature, although prices must be kept low enough so that they do not represent obstacles to anyone interested in viewing and enjoying the area.

Desirable patterns of visitor activity in these areas are developed schematically in the two accompanying diagrams. They show a logical movement of visitors through the areas, the activities in which visitors would engage, the public-use facilities needed to support these activities, and a variety of other aspects of visitor use.


VISITORS
La Parguera
Cabo Rojo
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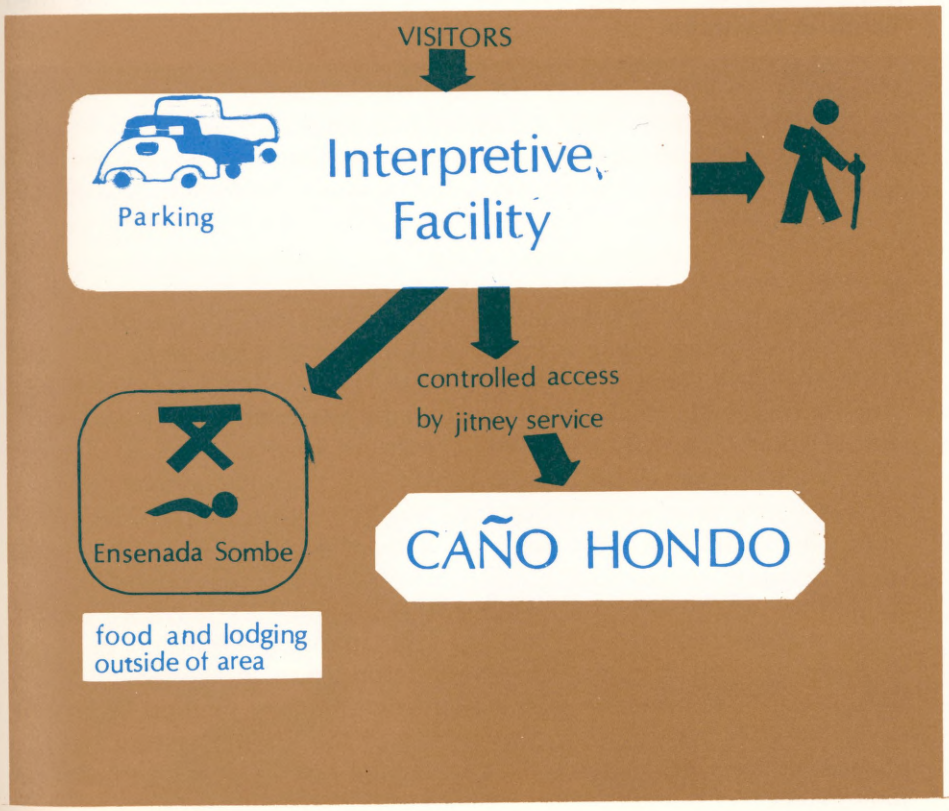
Private Marina
Coral Reefs
Interpretive Facility
Dock
controlled access
BIO-LUMINESCENT BAYS
Mangrove Swamps


VISITORS
Parking
Interpretive Facility
controlled access
by jitney service
Ensenada Sombe
CAÑO HONDO
food and lodging outside of area

The following comments refer to aspects of public use and interpretation shown in the diagrams.

(1) The bioluminescence of the bays is best viewed from a boat. The glow of boat wakes can be seen from the adjacent hills, but the sight is not impressive and does not merit special interpretive attention.

(2) The display of bioluminescence which the visitor sees is almost totally artificially stimulated. The movement of the tour boat through the bay agitates the waters to produce the typical glowing wake and phosphoreal bow waves. Fish as they flee the moving boat also form a characteristic aspect of the display. These views of bioluminescence should be enhanced by additional demonstration techniques, though all such demonstrations should be in good taste and in keeping with the naturalness of the phenomenon. Watching a person swim in the bay or towing a fine net behind the boat are just a few of the additional demonstrations that would be possible. Visitors should be allowed to handle the water of the bays, if only by reaching over the side of the boat and swirling their hands in the water.

(3) The 15- to 20-minute boat ride to the bays from La Parguera offers an excellent opportunity for an interpreter to impart a basic understanding of the phenomenon. Similarly, the return trip from the bays is available for interpretation. We recommend that a skilled interpreter accompany each tour boat and that this be the chief method of on-site interpretation.

(4) The open sea beyond the mouth of Caño Hondo is often too rough to allow for the comfortable passage of tour boats into and out of the bay. Thus the tour-boat arrangement needed here is different from that used in the sheltered waters at La Parguera. We suggest that the boat tours in Caño Hondo begin at a small dock within the bay itself. Visitors should be brought under carefully controlled conditions (perhaps aboard a bus or jitney) to the dock. A preliminary explanation of bioluminescence could be made here prior to boarding the boat, on the bus, or at a point removed from the bay shore, perhaps at the take-off point of the buses.

(5) Control of the kind and number of boats using the bays is essential to the maintenance of a suitable esthetic "atmosphere" within the bays. It is also desirable to insure adequate interpretation and suitable demonstrations of bioluminescence for all visitors. The best method of achieving these goals would be to limit access to the bioluminescent bays to government-regulated, concessioner-operated boats carrying professional interpreters.

(6) Interpretive tours of the coral reefs and mangrove swamps, as well as snorkel tours of reef features or combination boat-reef-wading trips, should be offered visitors in the La Parguera area. Concessioner boats with professional interpreters seem called for here also. While access to the bioluminescent bays should be limited to concessioner boats, such a limitation is not necessary for the reef and mangrove environments.

(7) At both La Parguera and Caño Hondo a central gathering point should be provided for visitor orientation and information. It should serve as a focus for activity in the area and should offer exhibits, audiovisual programs, publications, or other interpretive aids. Tours of the bioluminescent bays and environs should originate at such centers.

(8) The land adjacent to the bioluminescent bays offers fine opportunities for trail development and the interpretation of natural and historical features.

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Luminous waters swirl out behind a boat during a night tour.

Doused with buckets of water, this swimmer is outlined by the glow of millions of dinoflagellates.

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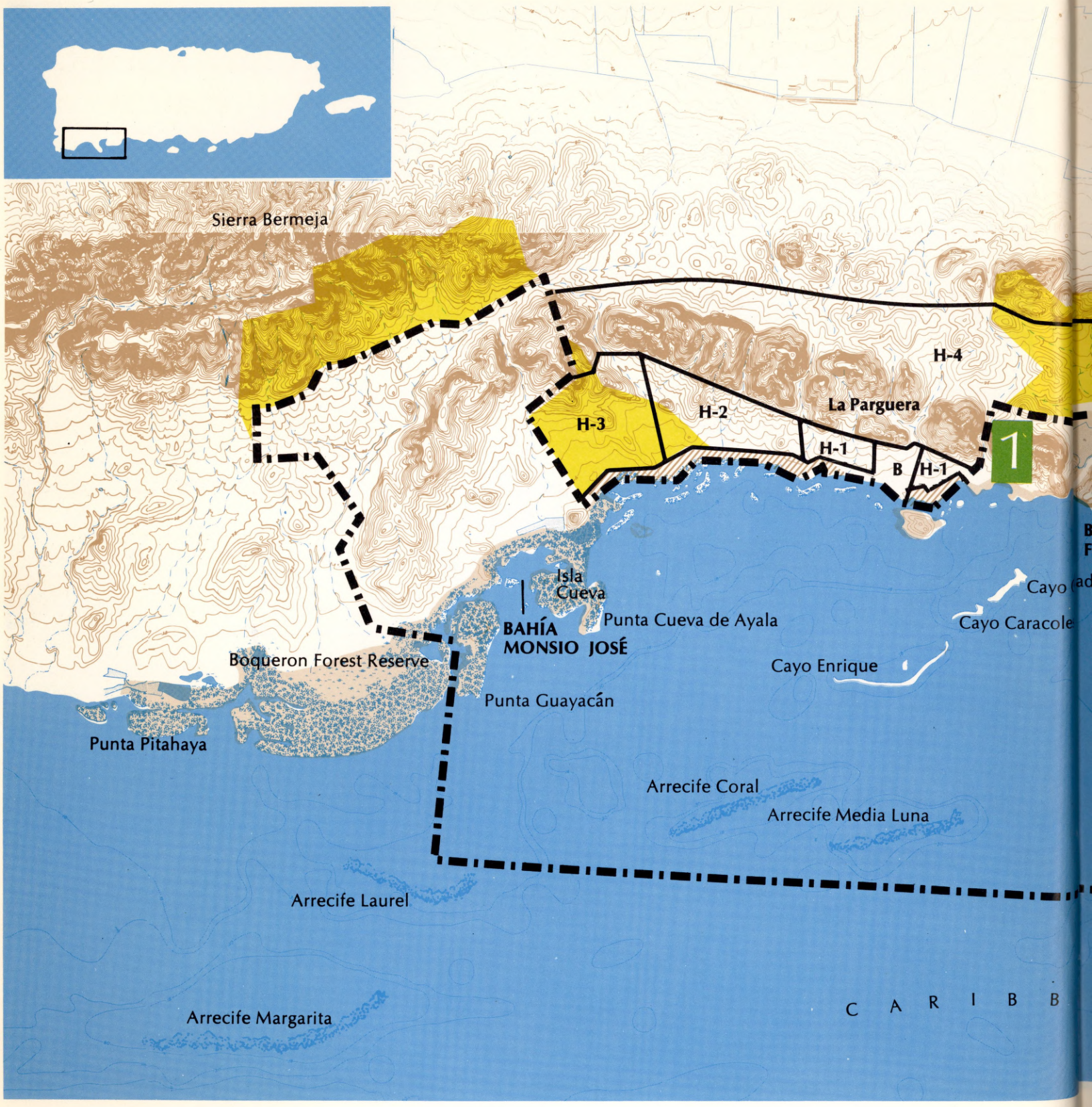
These plans provide for the preservation and use of Puerto Rico's magnificent bioluminescent bays as well as the outstanding coral reefs near La Parguera. A very generalized plan for the recreational use of the Cabo Rojo area to the west of La Parguera is also included. This latter area was not investigated in detail during this study, and the attached plan is intended only to indicate the broad area suitable for active recreational uses and the character that some of these uses and associated developments might have. The primary function of the Cabo Rojo area in this study is to absorb the pressures for active recreation that might normally be expected to focus at La Parguera.

Each plan is shown on a separate map and represents the logical outgrowth of the principles and recommendations outlined earlier. Two plans are presented for the La Parguera area and two for Caño Hondo. Essentially these represent a minimum workable proposal for each area and a larger, more comprehensive plan. The larger plan for each region will assure fuller control over environmental influences and provides a broader base for daytime visitor activities.

ACREAGE OF PLANS

	Area within proposed boundary			Zoned area outside proposed boundary
	LAND AREA	WATER AREA	TOTAL	
La Parguera Plan A	3,580	9,580	13,160	5,160
La Parguera Plan B	11,460	22,720	34,180	1,500
Caño Hondo, Plan A	1,540	1,320	2,860	4,630
Caño Hondo, Plan B	3,220	1,340	4,560	2,990
Cabo Rojo Plan	4,130	2,950	7,080	—

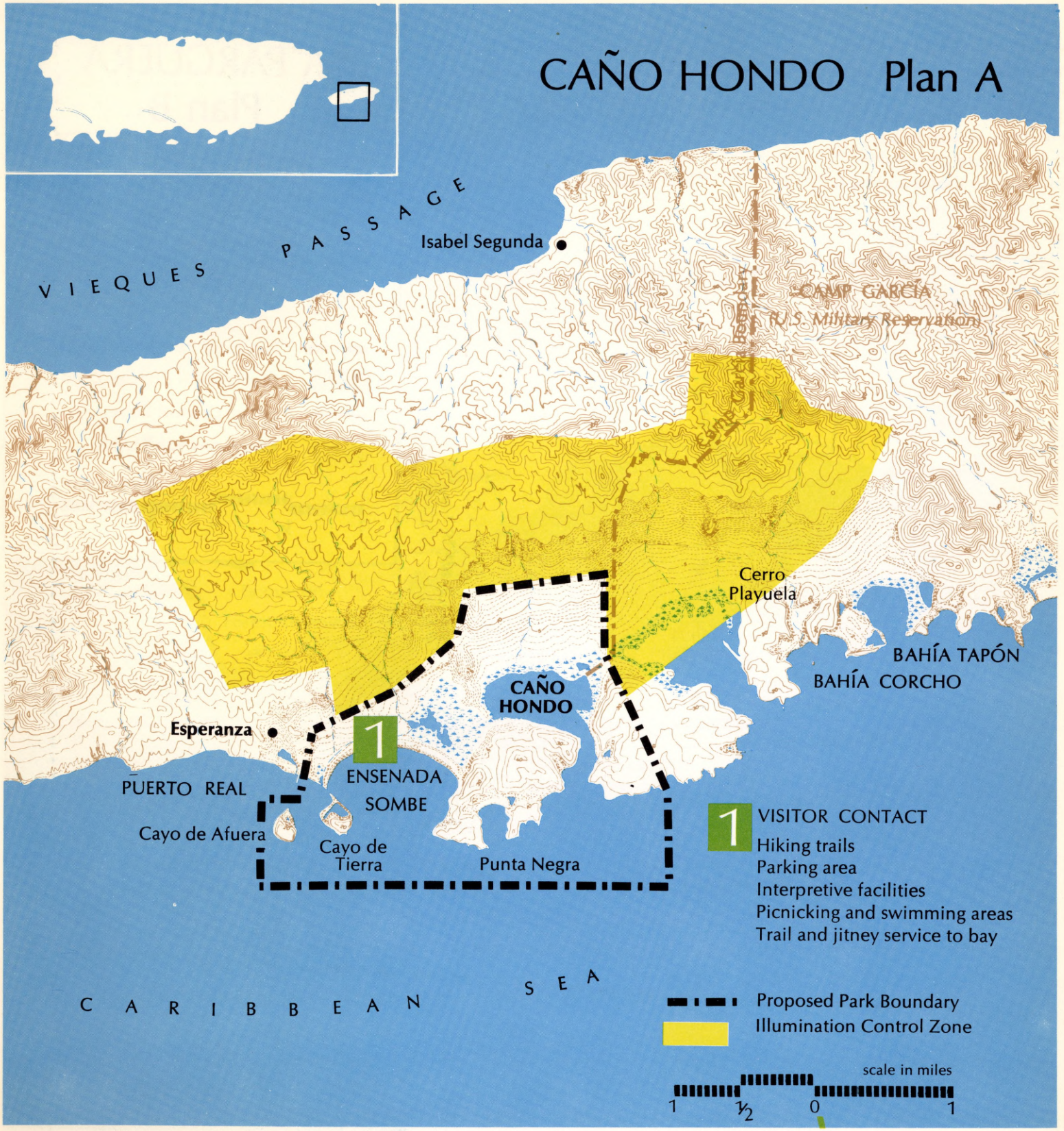
Because various combinations are possible, the total acreage is not given for any one plan.

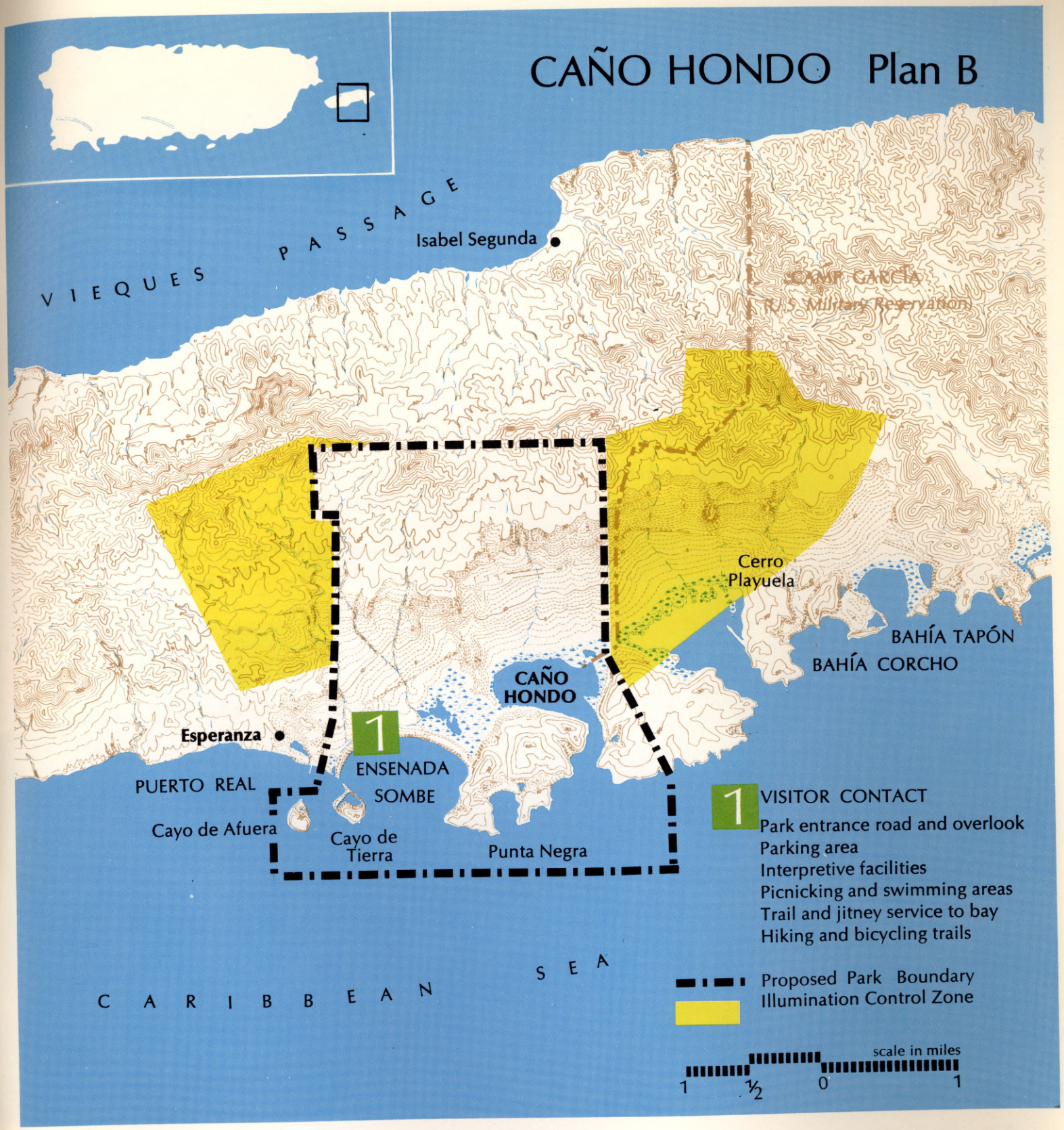

Sierra Bermeja
H-4
H-2
La Parguera
H-3
H-1
B
H-1
1
Isla
Cueva
Punta Cueva de Ayala
BAHÍA
MONSIO JOSÉ
Cayo Caracole
Boqueron Forest Reserve
Cayo Enrique
Punta Guayacán
Punta Pitahaya
Arrecife Coral
Arrecife Media Luna
Arrecife Laurel
Arrecife Margarita
C A R I B B

LA PARGUERA
Plan A
PROPOSED ZONING
B Commercial
H-1 Residential, 1/8-acre lot minimum
H-2 Residential, 1/4-acre lot minimum
H-3 Residential, 1-acre lot minimum
H-4 Semi-rural, 2-acre lot minimum
Public parks
Proposed Park Boundary
Illumination Control Zone
Urban Control Zone
Commonwealth lands
scale in miles
1/2
0
1
1
MAIN VISITOR CONTACT
Park entrance roads and parking area
Interpretive facilities
Overlooks, hiking trails, and jitney service to bays
Park dock and concession
Boat trips to shores and reefs
Snorkel trails
Cerro Vertero
BAHÍA FOSFORESCENTE
Isla Matei
BAHÍA MONTALVA
Punta Peñones
BAHÍA DE GUÁNICA
Arrecife Romero
Cayo Don Luis
ENSENADA LAS PARDAS
Arrecife Emmedio
Guánica Forest Reserve
Punta Brea
CARIBBEAN SEA

1
PALMAREJO DEVELOPED AREA
Park road and parking area
Camping facilities
Interpretive facilities
Boat access
Hiking, bicycling,
and horseback riding trails
Sierra Bermeja
H-2
H-3
1
La Parguera
H-1
B
H-1
2
Punta
Papayo
Cayo Collado
Cayo Caracoles
Isla
Cueva
Boqueron
Forest Reserve
BAHÍA
MONSIO JOSÉ
Cayo Enrique
Punta
Guayacán
Punta
Pitahaya
Arrecife Coral
Arrecife Media Luna
Arrecife Laurel
Arrecife Margarita
C A R I

2
MAIN VISITOR CONTACT
Park entrance roads and parking area
Interpretive facilities
Overlooks, hiking trails,
and jitney service to bays
Park dock and concession
Boat trips to shores and reefs
Snorkel trails
3
MONTALVA DEVELOPED AREA
Park road and parking area
Camping and picnic facilities
Interpretive facilities
Boat access
Hiking, bicycling,
and horseback riding trails
LA PARGUERA
Plan B
PROPOSED ZONING
B Commercial
H-1 Residential, 1/8-acre lot minimum
H-2 Residential, 1/4-acre lot minimum
H-3 Residential, 1-acre lot minimum
Public parks
Proposed Park Boundary
Illumination Control Zone
Urban Control Zone
Commonwealth lands
scale in miles
1 1/2 0 1
Cerro Vertero
Isla
Matei
BAHÍA
FOSFORESCENTE
BAHÍA MONTALVA
Salina
Vernales
3
Arrecife Romero
Arrecife Emmedio
Guánica
Forest Reserve
Cayo Don Luis
ENSENADA
LAS PARDAS
Punta
Brea
Punta
Jorobado
CARIBBEAN SEA


CAÑO HONDO Plan A
VIEQUES PASSAGE
Isabel Segunda
CAMP GARCÍA
(U.S. Military Reservation)
Cerro Playuela
BAHÍA TAPÓN
BAHÍA CORCHO
CAÑO HONDO
Esperanza
1
ENSENADA SOMBE
PUERTO REAL
Cayo de Afuera
Cayo de Tierra
Punta Negra
1 VISITOR CONTACT
Hiking trails
Parking area
Interpretive facilities
Picnicking and swimming areas
Trail and jitney service to bay
CARIBBEAN SEA
Proposed Park Boundary
Illumination Control Zone
scale in miles
1 ½ 0 1


CAÑO HONDO Plan B
VIEQUES PASSAGE
Isabel Segunda
CAMP GARCIA
(U.S. Military Reservation)
Cerro Playuela
BAHÍA TAPÓN
BAHÍA CORCHO
CAÑO HONDO
Esperanza
1
ENSENADA SOMBE
PUERTO REAL
Cayo de Afuera
Cayo de Tierra
Punta Negra
CARIBBEAN SEA
1 VISITOR CONTACT
Park entrance road and overlook
Parking area
Interpretive facilities
Picnicking and swimming areas
Trail and jitney service to bay
Hiking and bicycling trails
Proposed Park Boundary
Illumination Control Zone
scale in miles
1 ½ 0 1

BAHÍA DE BOQUERON
Laguna Rincón
Punta Moja Caseba
El Combate
Pole Ojea
1
2
BAHÍA SUCIA
Punta Aguila
BAHÍA SALINAS
CABO ROJO

CABO ROJO PLAN
Commonwealth lands
Proposed boundary
scale in miles
1
½
0
1
Sierra Bermeja
Proposed boundary
under
La Parguera Plan B
BAHÍA
MONSIO
JOSÉ
1
BOQUERON DEVELOPED AREAS
Park road and parking areas
Beach access points
Main visitor contact points
Interpretive facilities
Lodging concessions
Marinas and fishing facilities
Picknicking and camping areas
Swimming facilities
Hiking, bicycling, and horseback riding trails
Arrecife Laurel
2
CABO ROJO DEVELOPED AREAS
Park road and parking areas
Beach access points
Interpretive facilities
Picnicking and camping areas
Swimming facilities
Hiking, bicycling, and horseback riding trails
Arrecife Margarita

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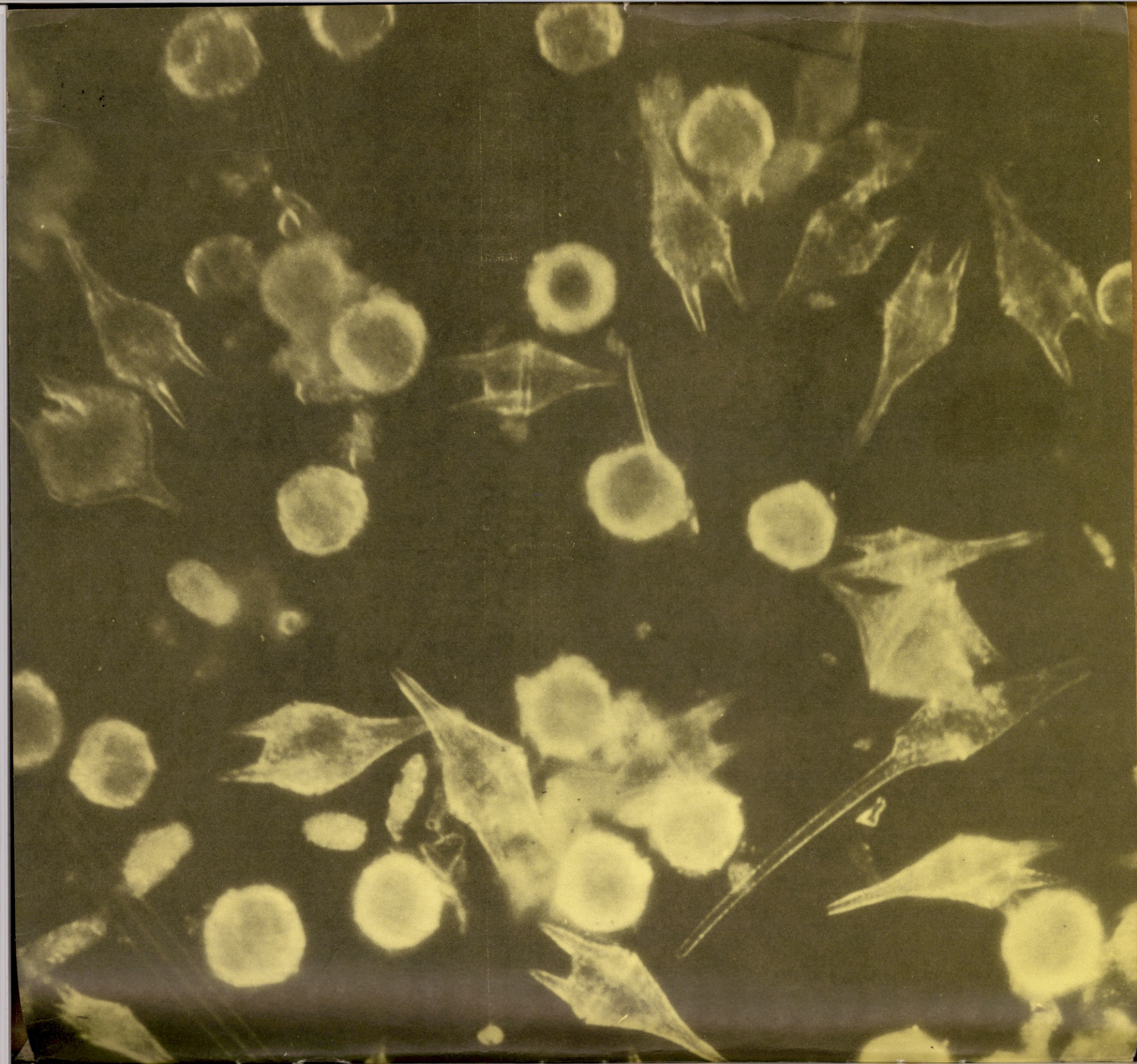
The Department of the Interior—the Nation's principal natural resource agency—works to assure that our expendable resources are conserved, that our renewable resources are managed to produce optimum benefits, and that all resources contribute to the progress and prosperity of the United States, now and in the future.

PHOTOGRAPHS
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